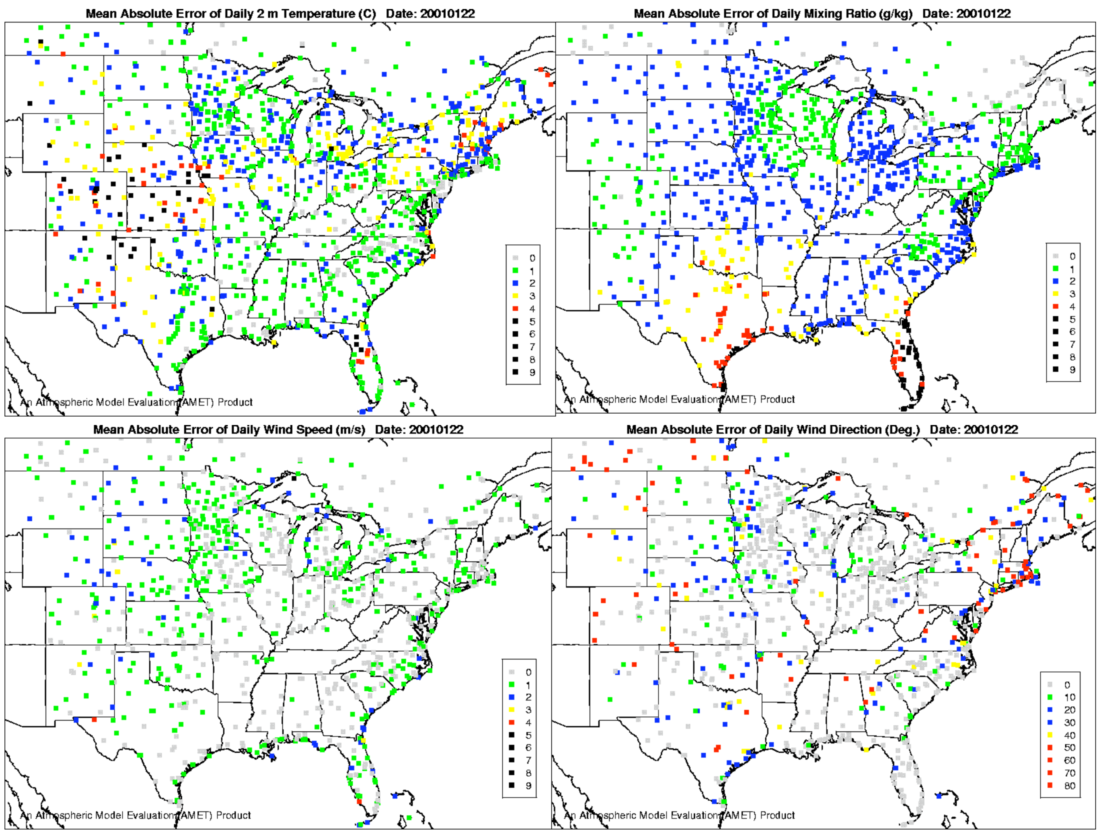
12km Model Performance Evaluation for an Annual MM5 Simulation



Pat Dolwick, Rob Gilliam (NOAA/EPA), and Dennis McNally (Alpine Geophysics)

Ad Hoc Meteorological Modeling Meeting – 6/30/2005

Outline

- Protocol for evaluating meteorological modeling input data to AQM
  - **Changes to AQ modeling guidance**
  - **Operational evaluation**
  - **Phenomenological evaluation**
  - **Blending the meteorological evaluation results w/ the AQM results**
- Description of 2001 12km MM5 modeling application
- Results from 2001 12km MM5 modeling application

Evaluation of Meteorological Modeling

- Guidance rewritten to incorporate many of the latest findings re: evaluation of meteorological modeling. Influenced by several documents:
  - **Tesche et al (2002): "Operational evaluation of the MM5 meteorological model over the continental United States: Protocol for annual and episodic evaluation."**
  - **Emery and Tai (2001): "Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes."**
  - **Numerous MM5 evaluations: (e.g., Olerud et al., 2000; Doty et al., 2001; Johnson, 2003; Baker, 2004; Gilliam, 2004).**

- AQMs used in attainment demonstrations have consistently been subjected to a rigorous performance assessment, but in many cases the meteorological inputs to these models are accepted <u>as is</u>, even though this component of the modeling arguably contains a <u>higher quantity of potential errors that could affect the results of the analysis</u> (Tesche, 2002).

Evaluation of Meteorological Modeling

- Evaluation goal is to
  - **move away from "as is" acceptance of meteorological inputs and**
  - **move toward an understanding of how the bias & error of the meteorological data affect the resultant AQM simulations.**

- Two specific evaluation objectives:
  - **1) Determine if the meteorological model output fields represent a *reasonable approximation of the actual meteorology* that occurred during the modeling period. (Operational evaluation)**

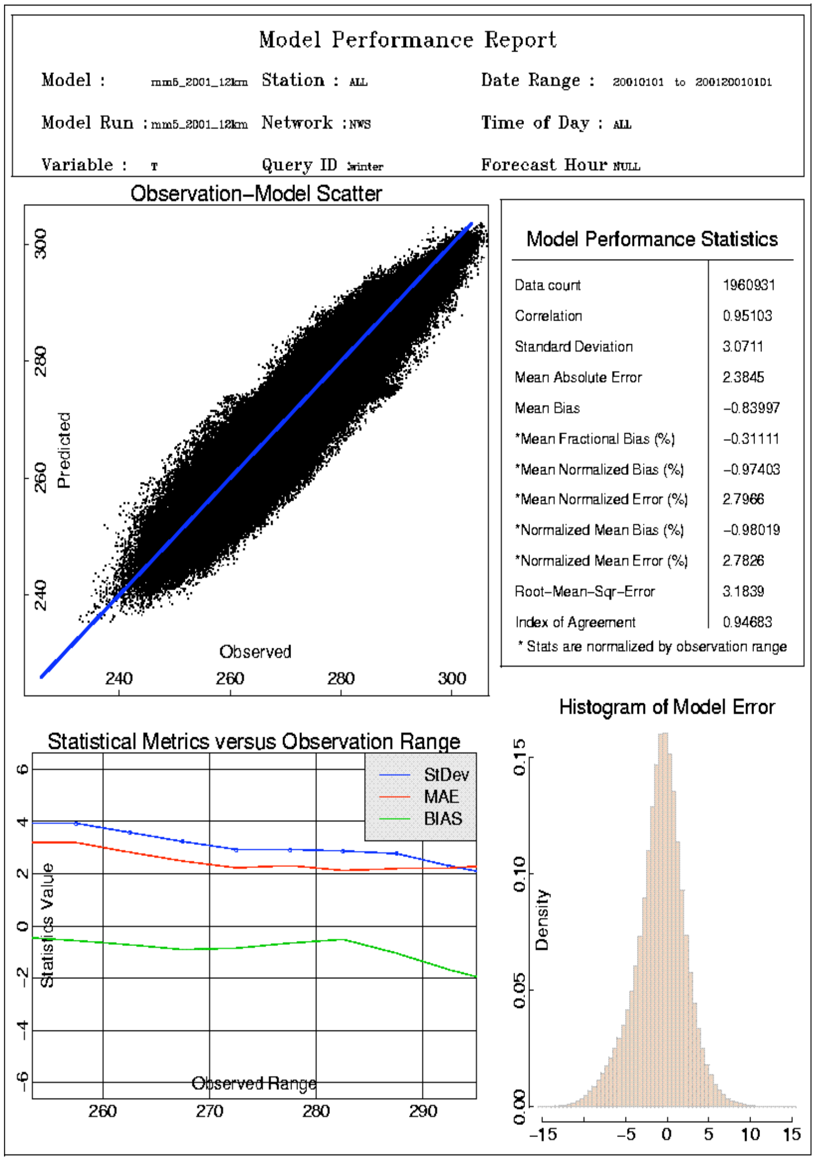
  - **2) Identify and quantify the existing biases and errors in the meteorological predictions in order to allow for an downstream *assessment of how the air quality modeling results are affected* by issues associated with the meteorological data. (Phenomenological evaluation)**

Operational Evaluation

- **Statistical Measures:**
  - comparisons of the means,
  - mean bias, mean normalized bias,
  - mean absolute error, mean absolute normalized error, RMSE (s & u), and
  - index of agreement.

- **Met Parameters:**
  - temperature, water vapor mixing ratios
  - wind speed / wind direction
  - clouds / radiation, precipitation
  - PBL (max, time series evolution)

- **Segmented evaluation:**
  - geographic subregions, episodes,
  - aloft vs. surface, diurnal cycle
  - as a function of synoptic regimes



Operational Evaluation

- Whenever possible, met modelers should try to set aside a portion of the ambient data strictly for evaluation purposes.
- Qualitative comparisons can be useful.
- Evaluation should take place not only on the raw meteorological outputs, but on the post-processed meteorology as well.
- What about the use of performance benchmarks?
  - **Can help with the initial objective of assessing general confidence in the meteorological model data, however …**
  - **EPA has concerns about potentially misleading comparisons of model performance findings across different analyses w/ differing model configurations and FDDA strengths, therefore …**
  - **while we plan to compare the statistical evaluation outputs back against a set of performance benchmarks, we do not recommend the results of these comparisons be used in a pass/fail mode.**

Phenomenological Evaluation

- Components of the evaluation should be tied to the conceptual model of the AQ issue being considered:
  - **For example, if a sea breeze is an important regulator of where and when ozone is formed, then the phenomenological evaluation should assess the ability of the meteorological model to reproduce this feature in space/time**

- Other possible elements of a phenomenological evaluation include:
  - **Comparison of model trajectories vs. “actual” trajectories (transport)**
  - **Existence of a low-level jet in model / ambient**
  - **Ability of the model to capture frontal passages, airmass residence time**

- Because of the event-oriented nature of the phenomenological evaluation, one will need to summarize model performance in terms of a different suite of statistical metrics: e.g., probability of detection and false alarm rate.

Blending the Meteorological Evaluation Results w/ the AQM results

- Armed with the results of the operational and phenomenological evaluation results, one should have an idea of the strengths and weakness of the model.

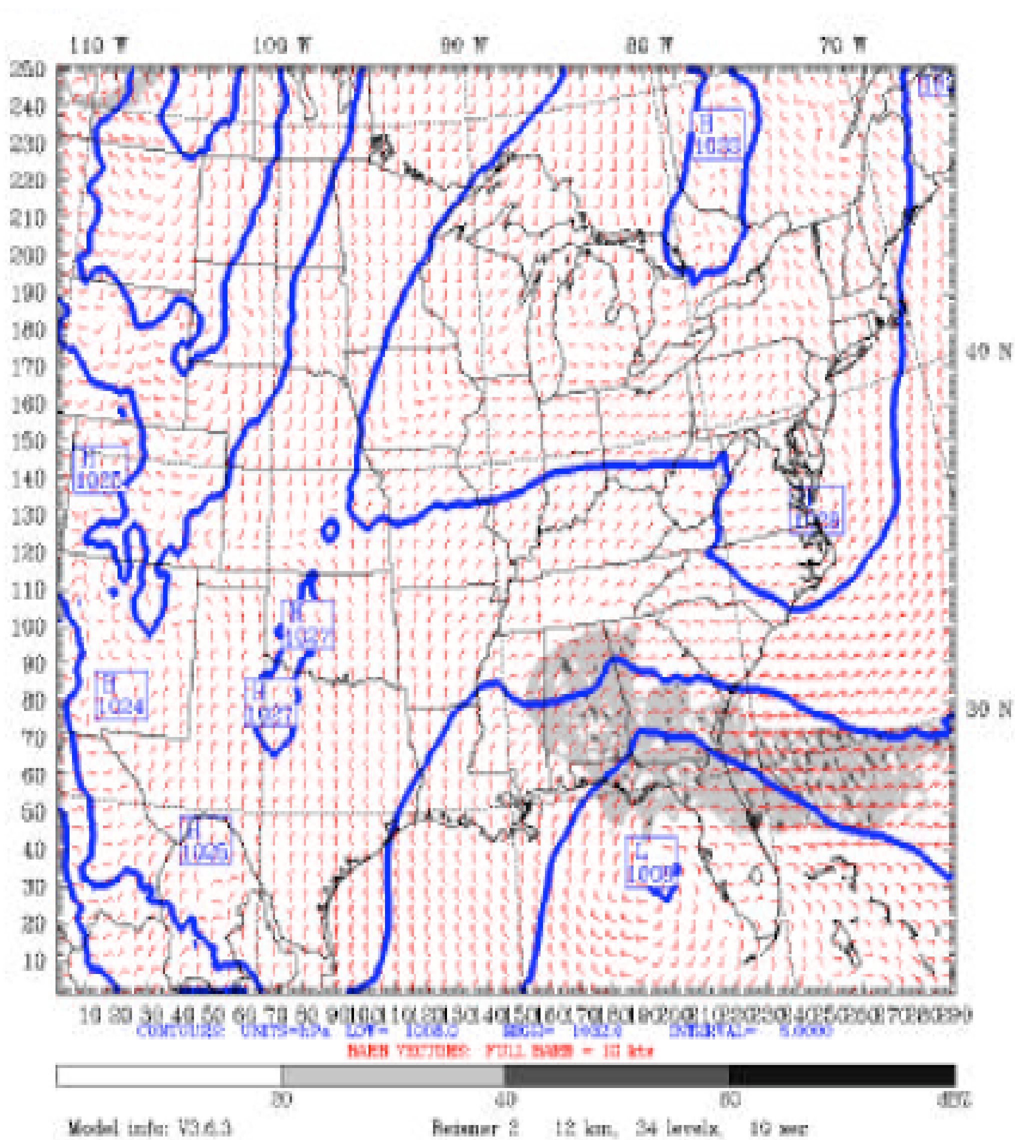
- The evaluation results can be used to guide AQ modelers as to those regions/periods/regimes where model performance is optimized, yielding more certain AQM projections.

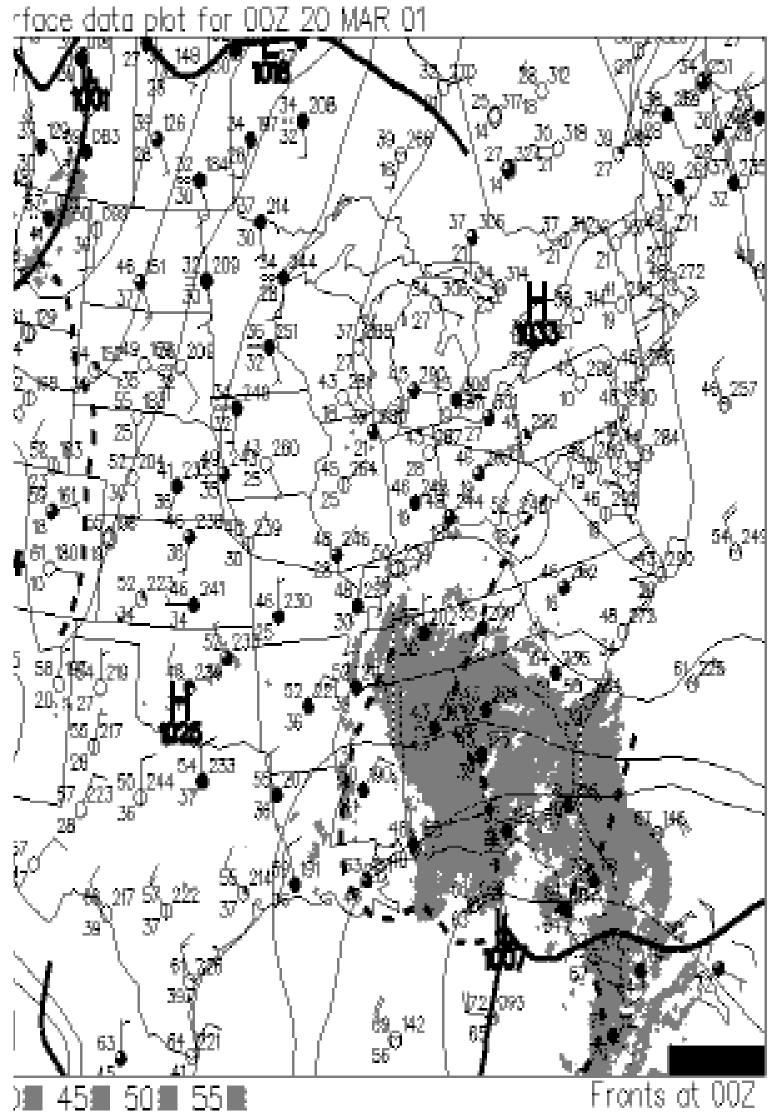
- EPA 2001 evaluation has been oriented toward providing “sound bite” information to AQ modelers.
  - **Challenge is sorting through the thousands of plots to develop a comprehensive but digestible understanding of meteorological model performance.**
  - **Last slide highlights most important conclusions from meteorological modeling evaluation.**

2001 12km MM5 modeling application

- **Model version 3.6.3 (minor fixes to KF2 & Reisner 2)**
- **Modeling conducted by Alpine Geophysics**
- **Physics Options:**
  - **Radiation: RRTMLW (IFRAD = 4)**
  - **Cumulus Parametrization: Kain-Fritsch2 (ICUPA = 8)**
  - **Microphysics: Reisner 2 (IMPHYS = 7)**
  - **Land Surface Model: Pleim-Xiu (ISOIL = 3)**
  - **PBL Scheme: Pleim-Chang (IBLTYP = 7)**
  - **Snow cover effects considered (IFSNOW = 1)**
  - **ISSTVAR =1, SST varying in time**
  - **RADFRQ = 15, frequency that solar radiation is computed**
- **Analysis Nudging (12km):**
  - **winds (aloft): 1.0E-4; winds (surface): 1.0E-4,**
  - **temperature (aloft): 1.0E-4; temperature (surface): N/A**
  - **moisture (aloft): 1.0E-5; moisture (surface): N/A**
- **P-X Details:**
  - **use interppx (moisture only) - runs initialized from previous runs -- 10 day spinup**
  - **use current version of code (3.6.1)**
  - **use "nest-PX" instead of nestdown for soil info.**
- **Run Durations: 5.5 day individual runs, w/in 7 two-month simulations**

Qualitative Evaluation 2001 12km MM5:
Sample hour: 3/20/2001 (00 UTC)





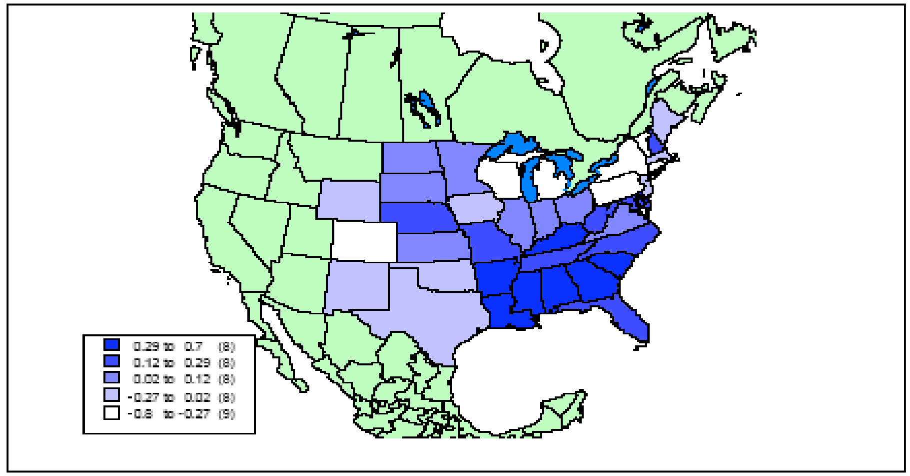
Operational Evaluation 2001 12km MM5: Temperature

- **Model is unbiased for temperature at large scale**
  - **0.01 K for entire year (all 9 million hourly obs)**
- **Bias/error is a function of season**
  - **Underprediction in winter (0.84K); worst in January**
  - **Overprediction in spring/summer (~0.40K); worst in May**
- **Bias/error is a function of region.**
  - **Overestimation most common in Southeast**
  - **Underestimation in Western regions, Great Lakes States**
- **Bias/error is a function of time of day.**
  - **Overpredict at night, underpredict during the day (worst in summer)**
- **Bias/error is a function of concentration range.**
  - **Low values are overpredicted; high values are underpredicted**

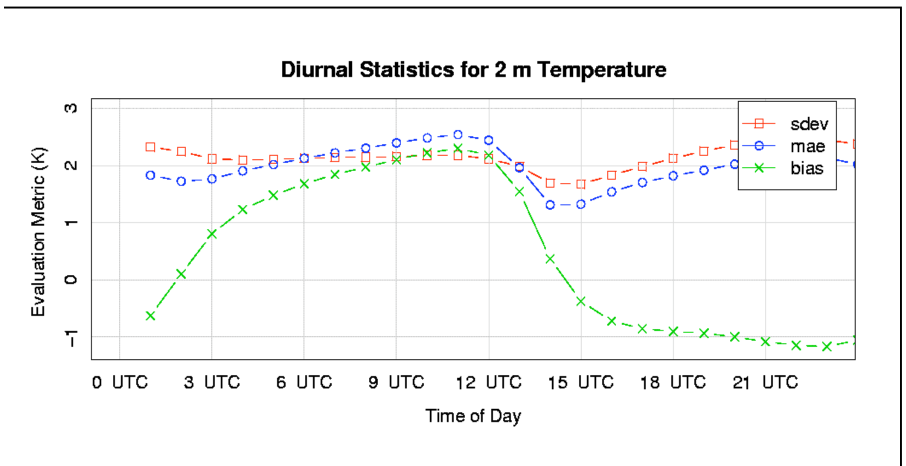
Operational Evaluation 2001 12km MM5: Temperature

Mean Bias (Mod-Obs)

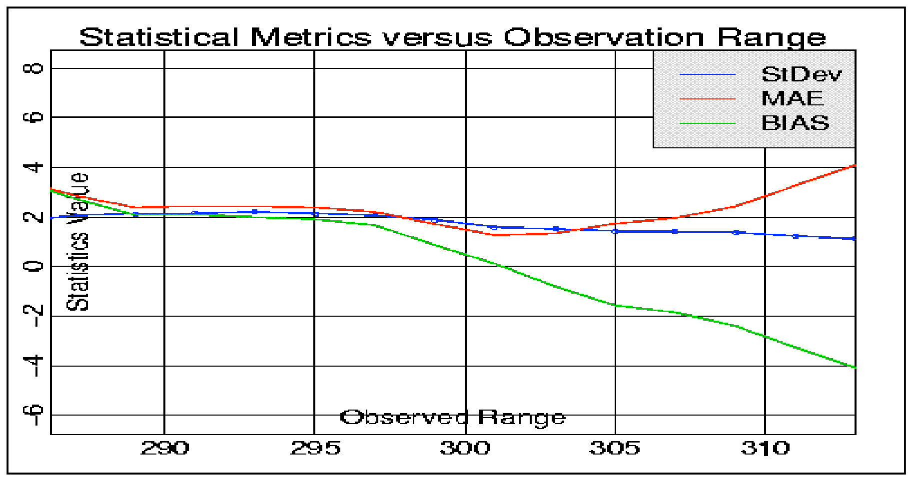
	2m Temp
winter	-0.84
spring	0.43
summer	0.38
fall	-0.06



(Average T bias)



(Summer)



(Desert)

Operational Evaluation 2001 12km MM5:
Water Vapor Mixing Ratio

- ***Placeholder***

Operational Evaluation 2001 12km MM5:
Water Vapor Mixing Ratio

- ***Placeholder***

Operational Evaluation 2001 12km MM5:
Wind Speed / Wind Direction

- **Model is generally unbiased for wind speed/direction (domainwide)**
  - **Seasonal speed biases always < +/- 0.1 m/s; error ~ 1.25 m/s**
  - **Seasonal directional biases < 5 degrees; error ~30-40 degrees.**
  - **Bias/error doesn’t vary significantly by season**

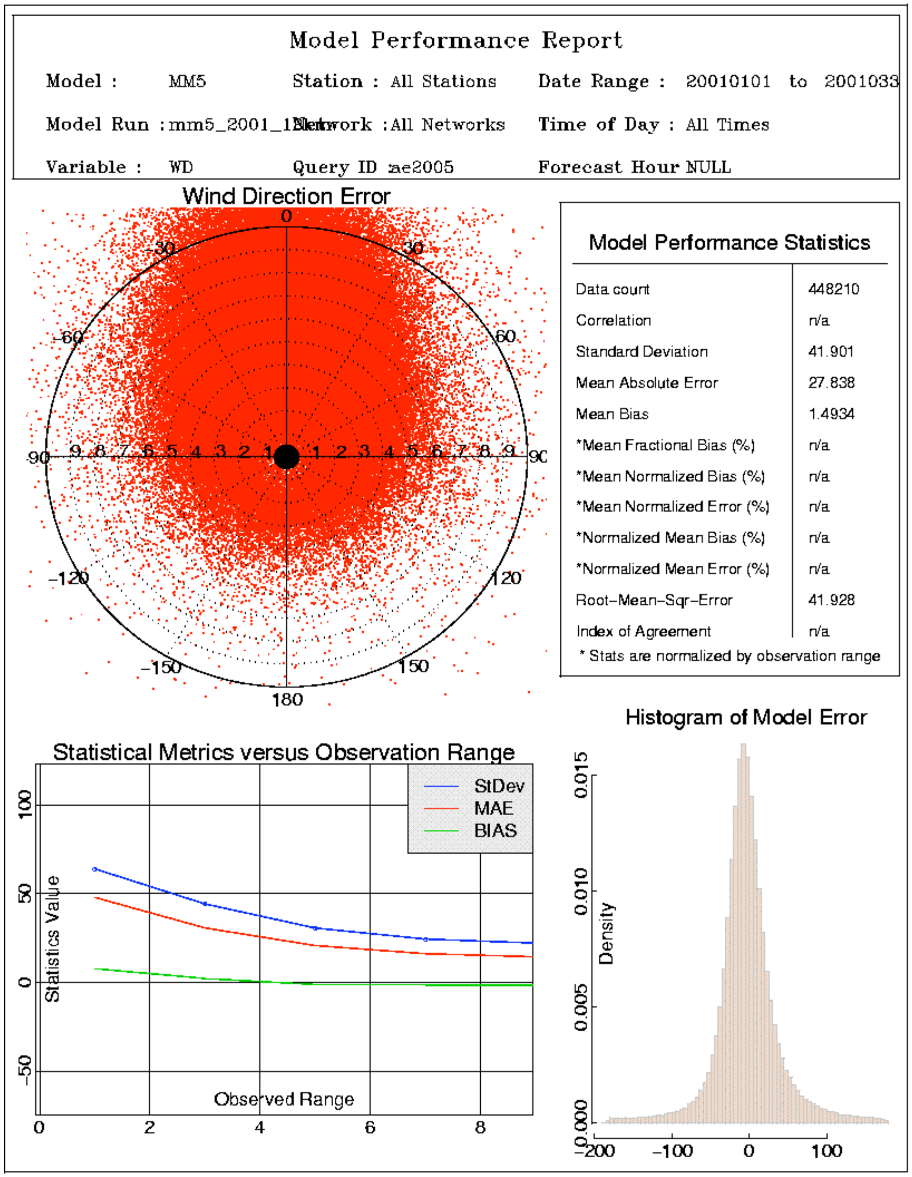
- **Bias/error is a function of region and landuse.**
  - **Poorest performance in the terrain-influenced Rockies (underestimation)**
  - **Overpredict speed over water; underpredict speed w/in urban**

- **Bias/error is a function of time of day.**
  - **Overpredict at night, underpredict during the day (after inversion breakup)**

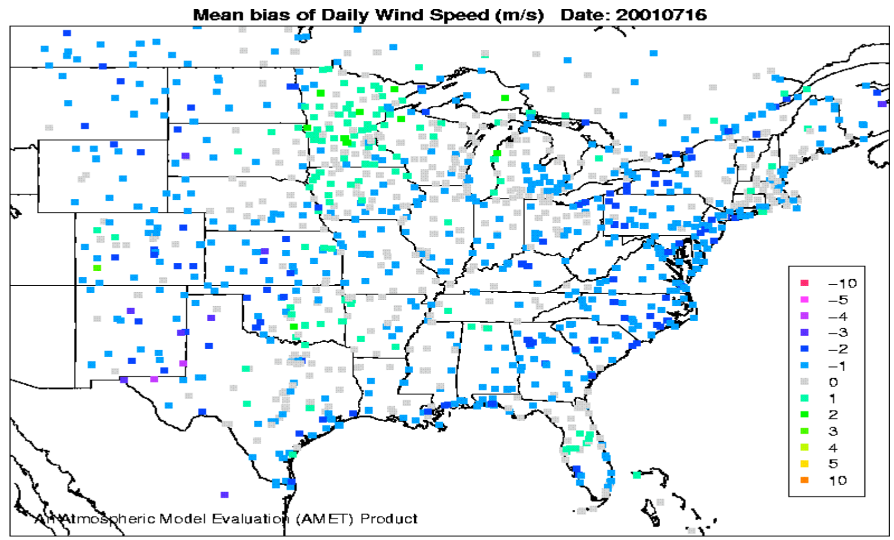
- **Bias/error is a mild function of concentration range.**
  - **Low speed values are overpredicted; high speed values are underpredicted**

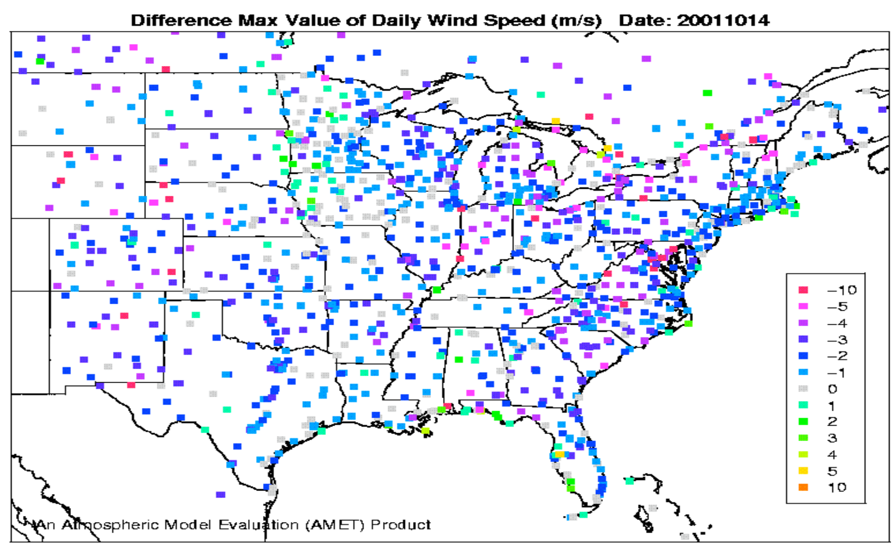
Operational Evaluation 2001 12km MM5:

Wind Speed & Direction



Jan-Mar 2001

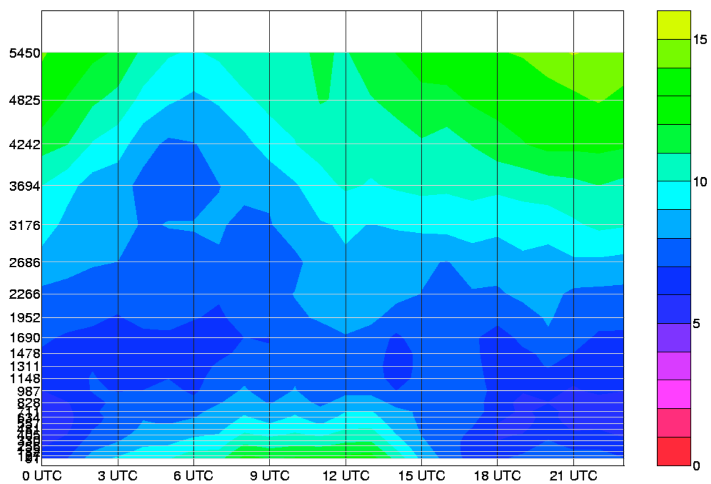




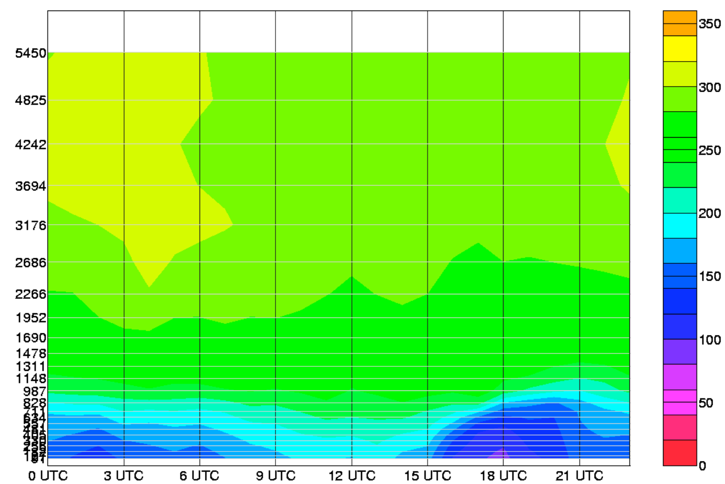
Operational Evaluation 2001 12km MM5:
Wind Speed & Direction: Profiler data (Iowa/July)

OBS

Time–Height Mean Observation of Wind Speed (m/s)

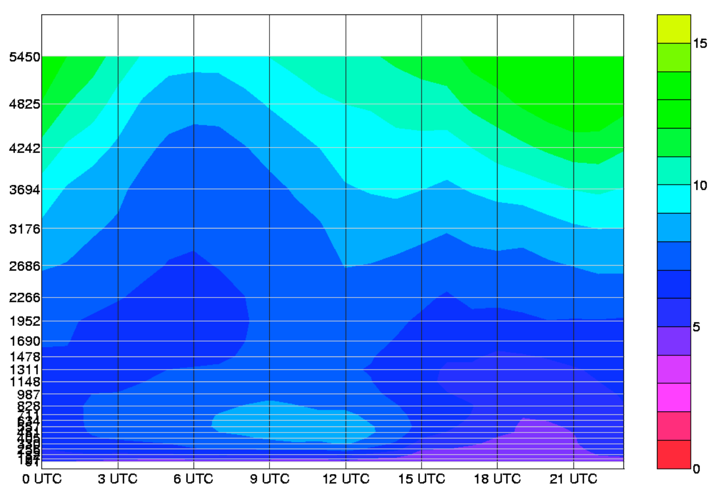


Time–Height Mean Observation of Wind Direction (Deg)

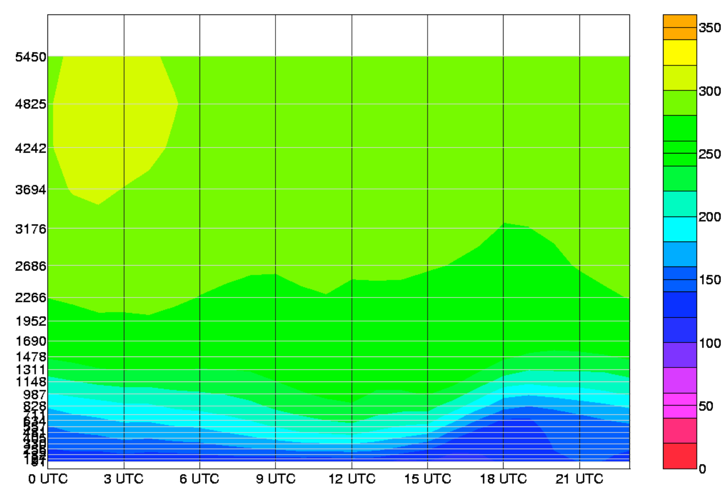


MOD

Time–Height Mean Model of Wind Speed (m/s)

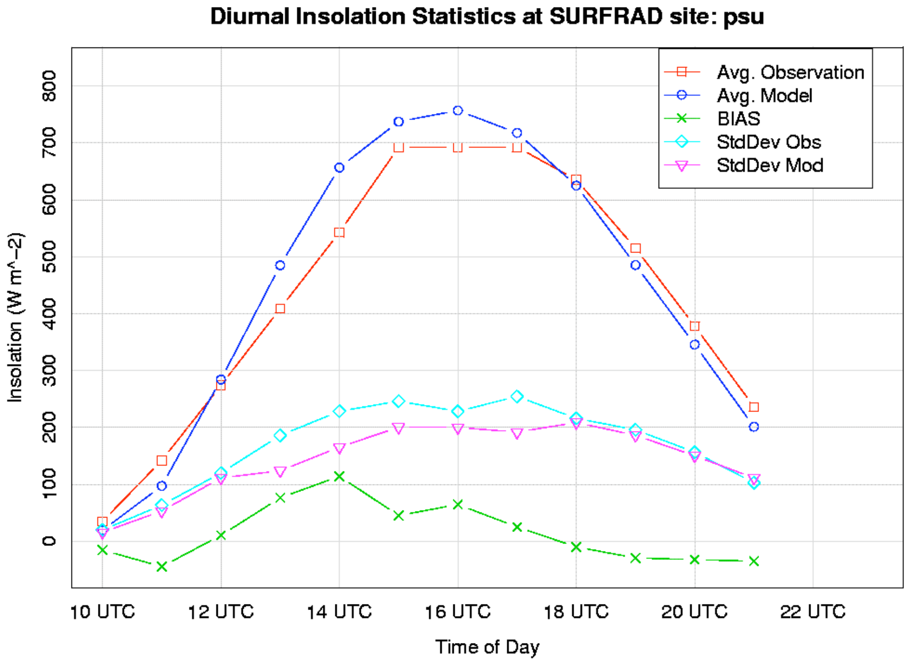


Time–Height Mean Model of Wind Direction (Deg)

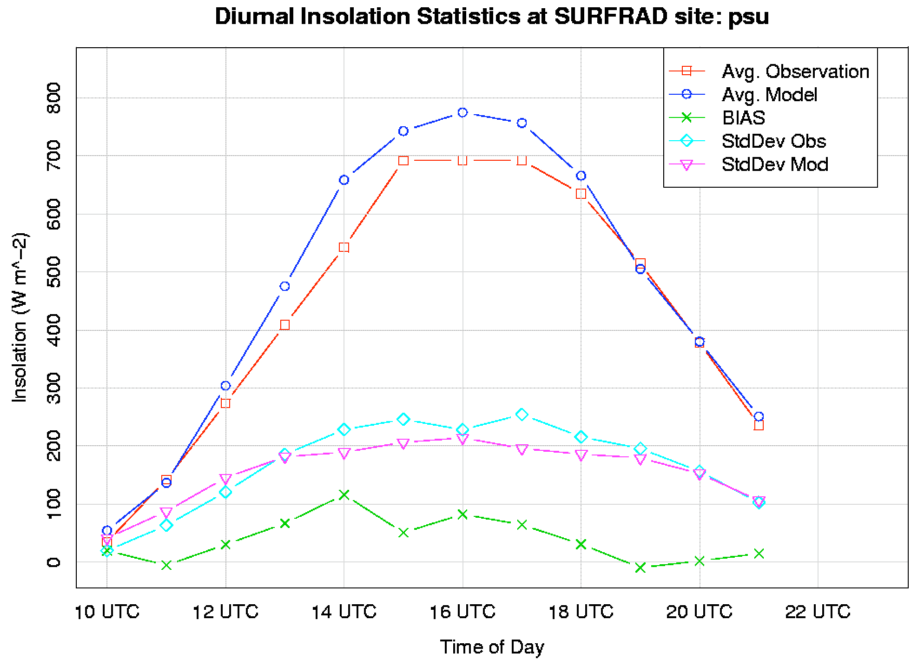


Operational Evaluation 2001 12km MM5:
Clouds/Radiation

MM5 (36 km) August, 2001



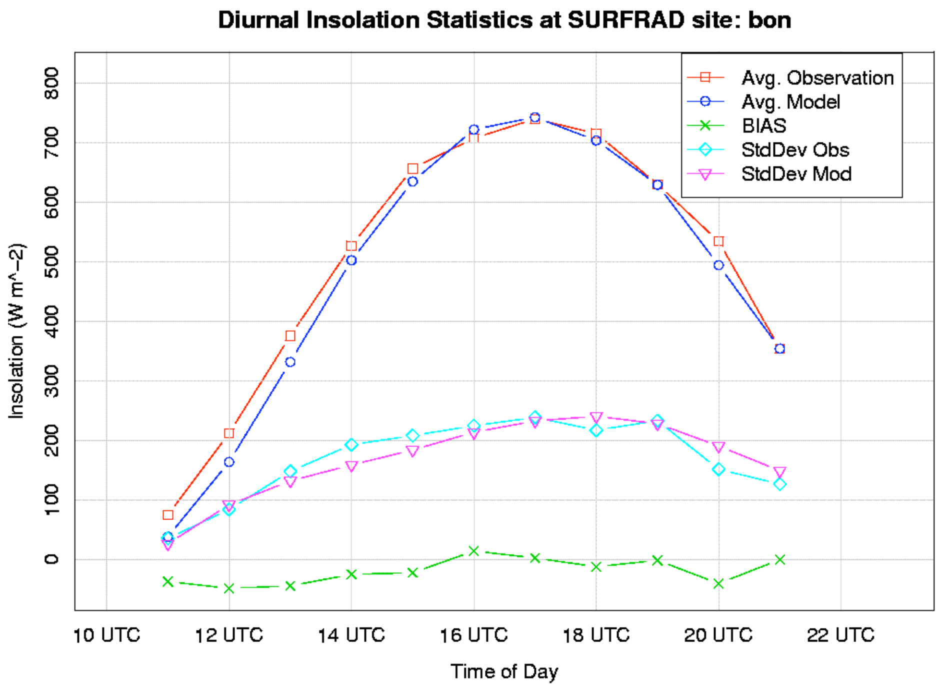
MM5 (12 km) August, 2001



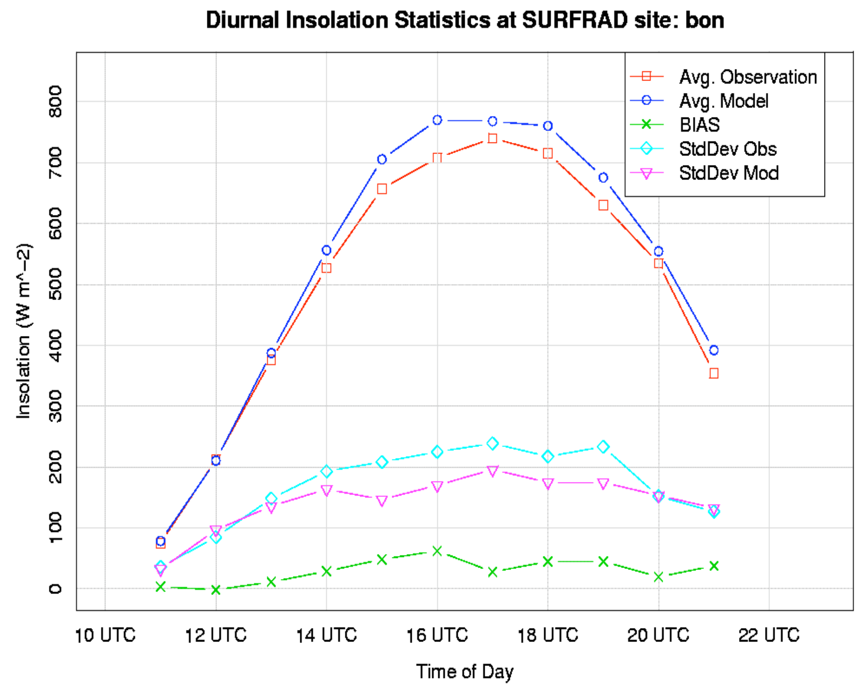
State College, PA

Operational Evaluation 2001 12km MM5:
Clouds/Radiation

MM5 (36 km) August, 2001



MM5 (12 km) August, 2001



Bondville, IL

Operational Evaluation 2001 12km MM5: Precipitation

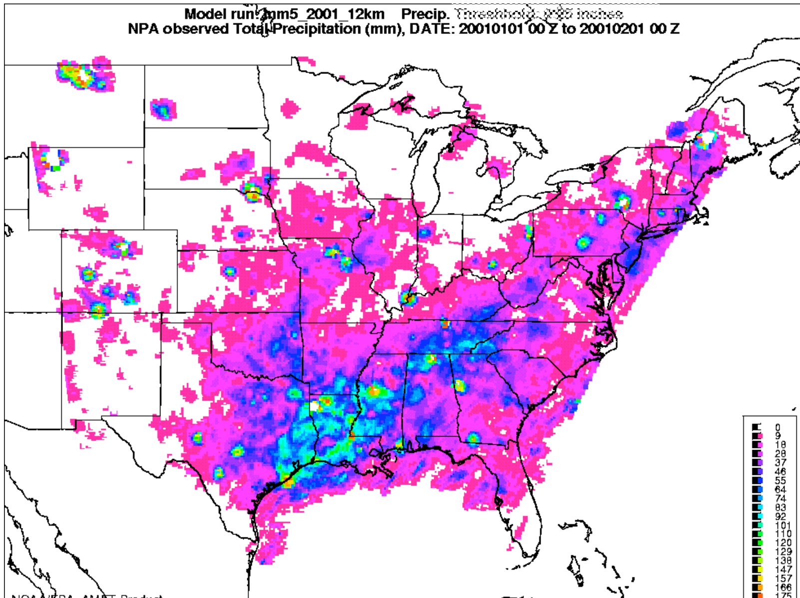
- **Model is generally unbiased for precipitation at large scale, however individual model/obs comparisons in space/time can show large deviations.**

- **Bias/error appears to be a function of season.**
  - **Overpredictions & underpredictions are most common in the summer**
  - **Wintertime performance appears best**

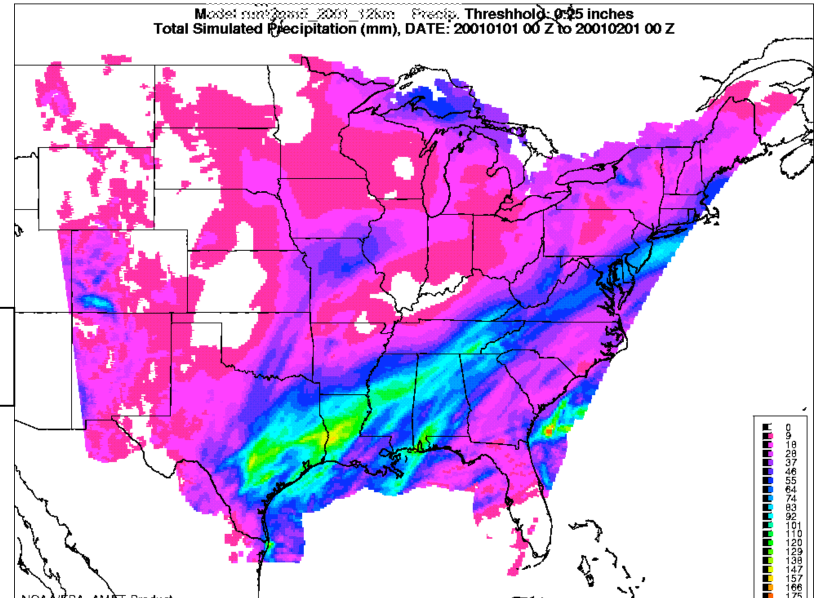
- **Bias/error does not appear to be a function of region.**

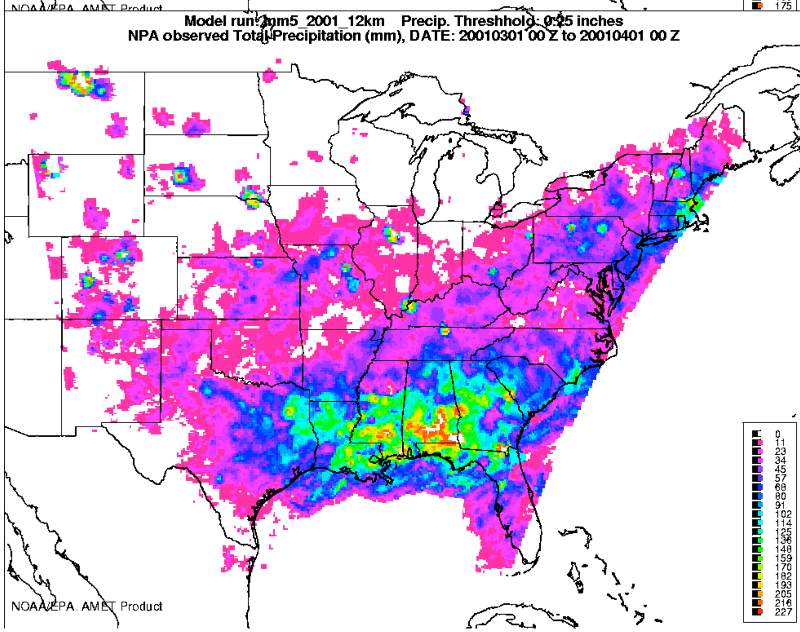
Operational Evaluation 2001 12km MM5:
Precipitation

Obs | **Model**

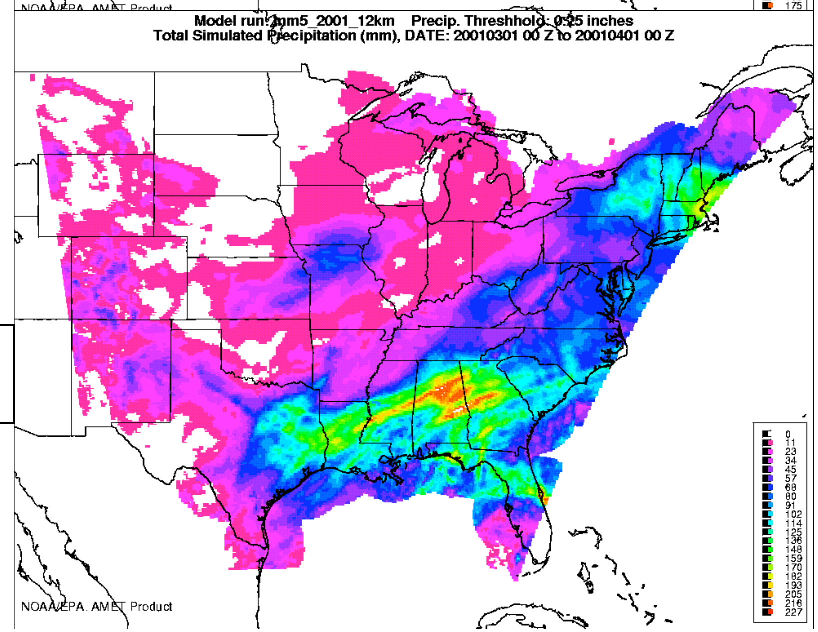


Jan





Mar

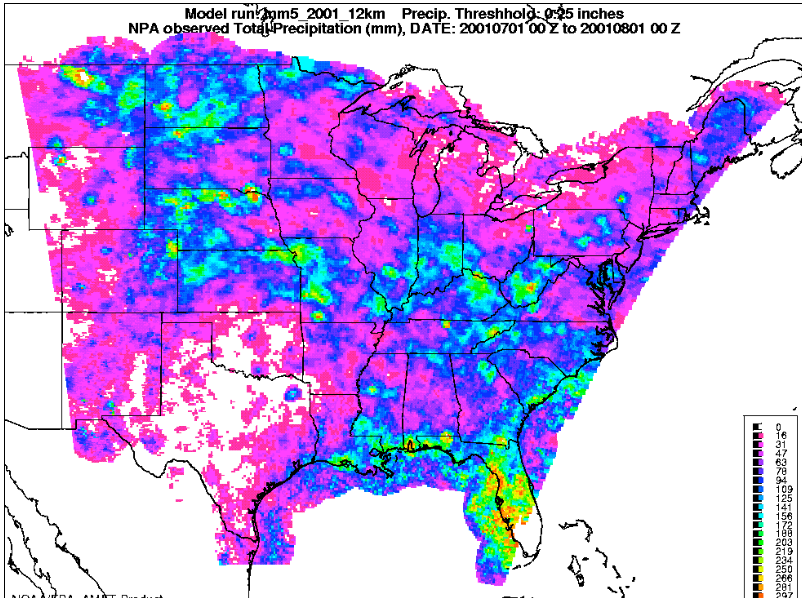


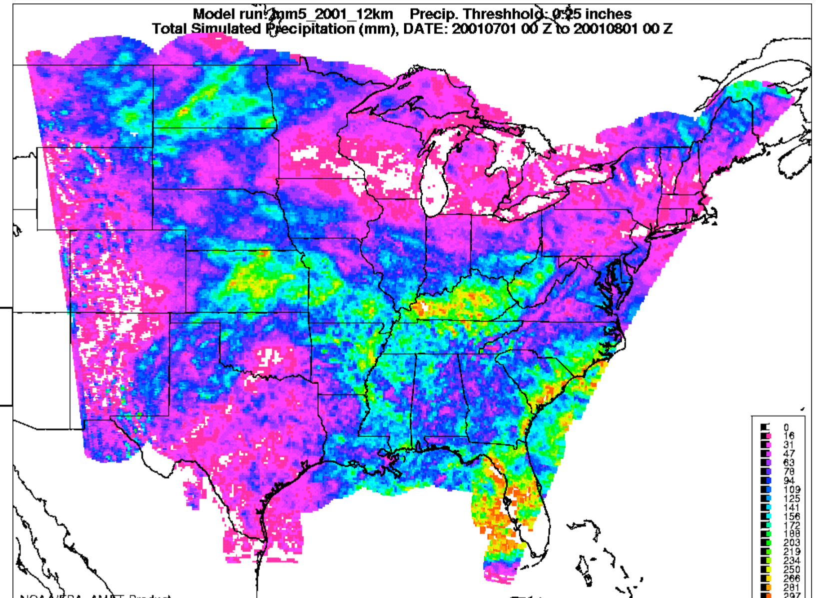
Operational Evaluation 2001 12km MM5:

Precipitation

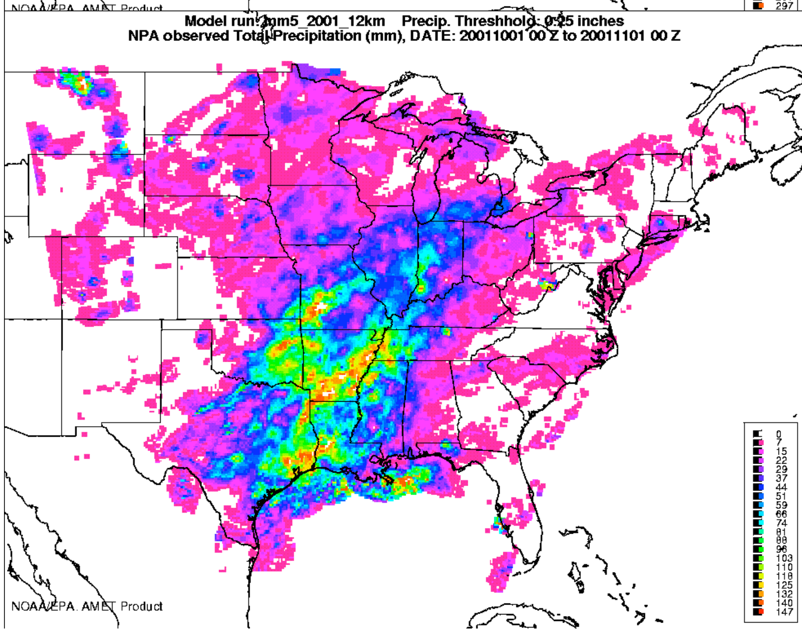
Obs | **Model**

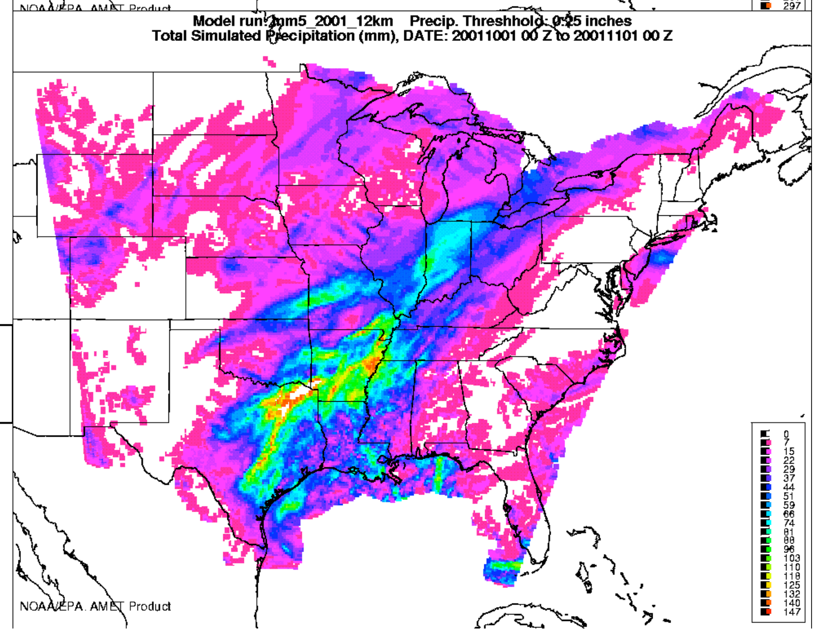
Jul





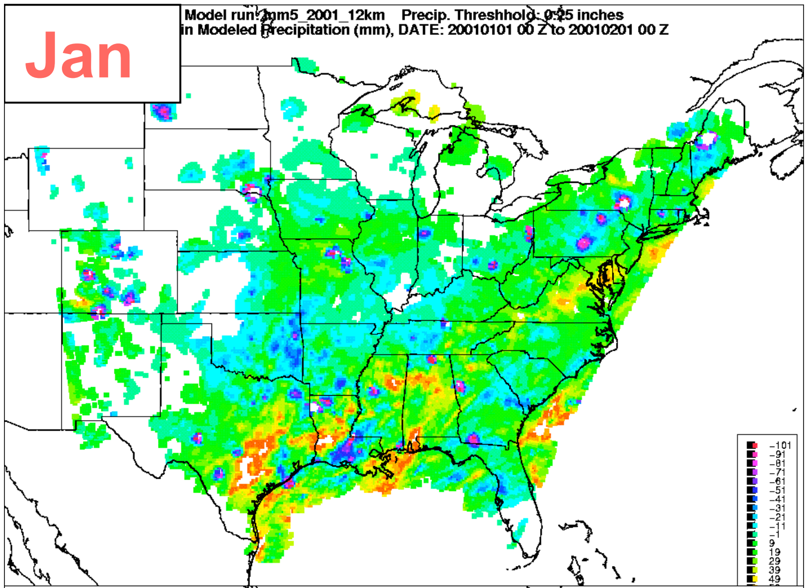
Oct

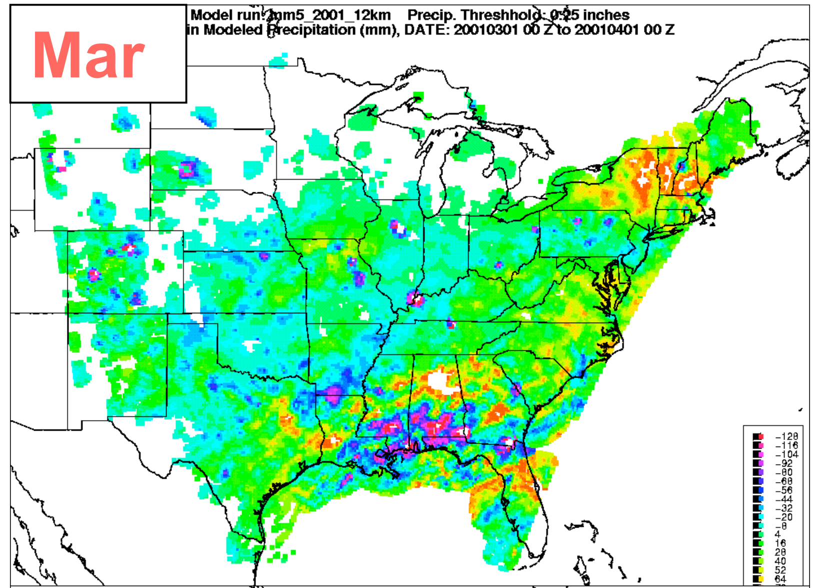


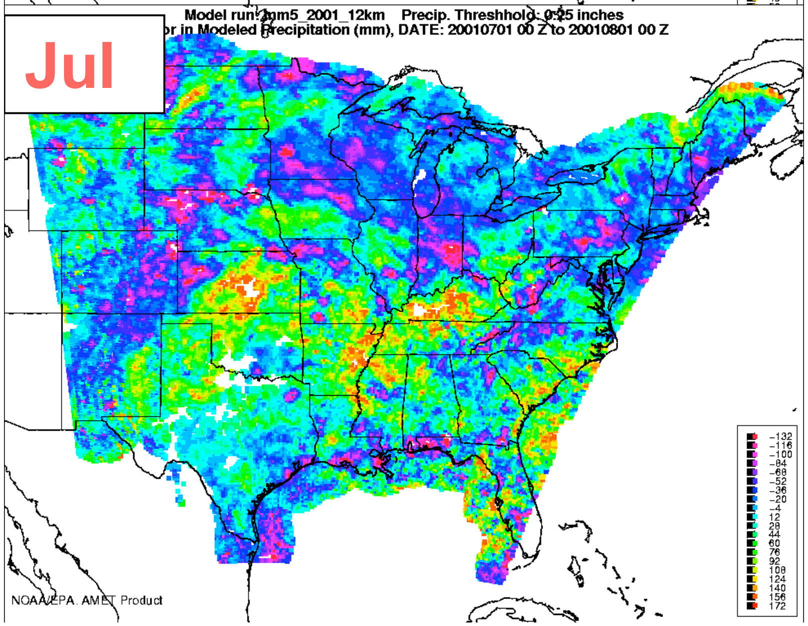


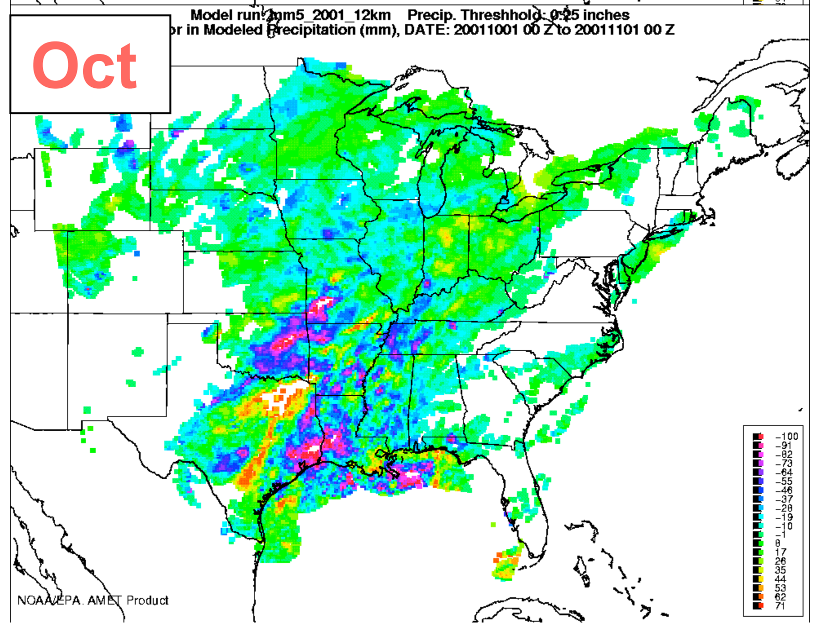
Operational Evaluation 2001 12km MM5:

Precipitation

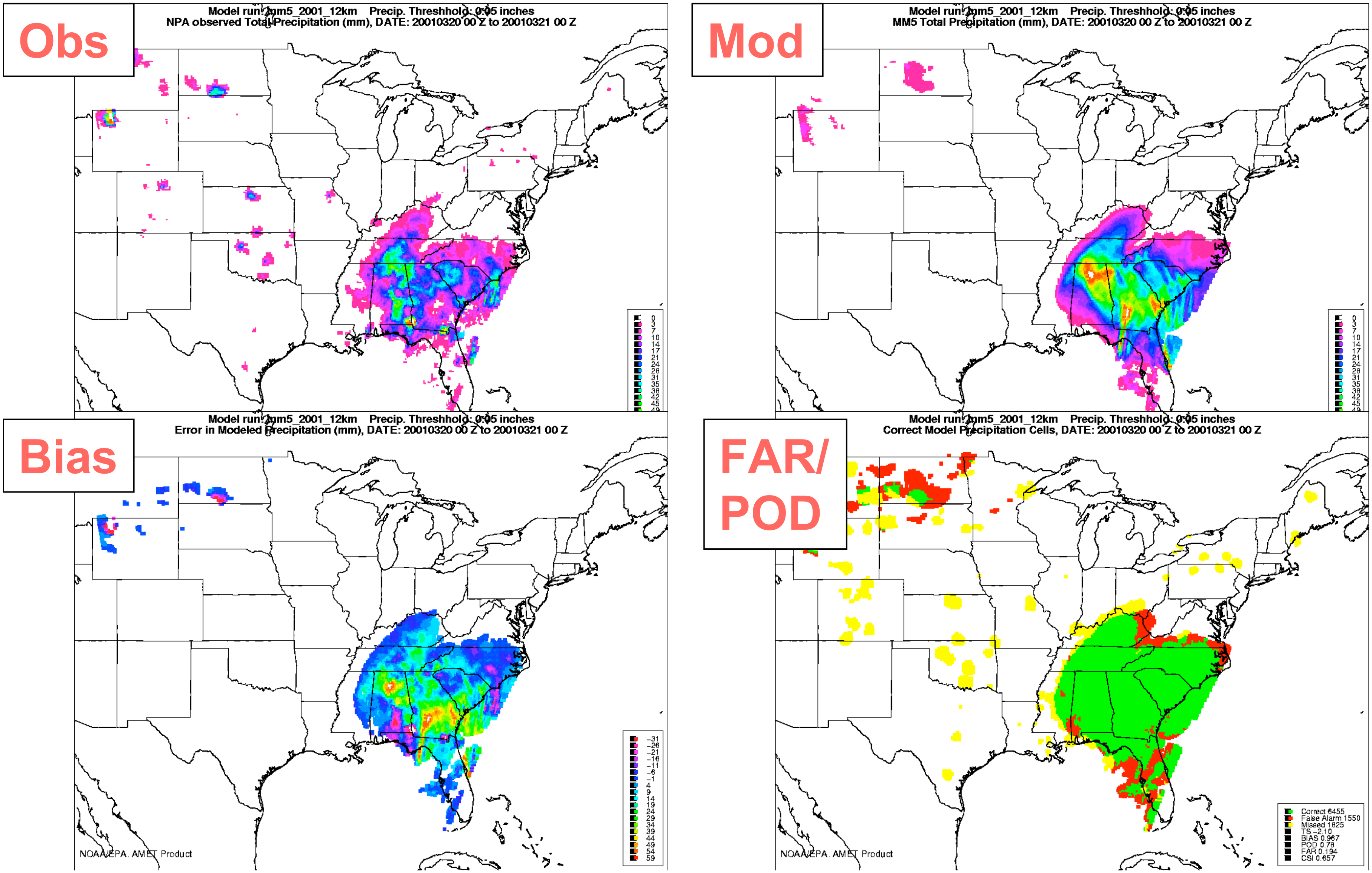








Operational Evaluation 2001 12km MM5:
Precipitation



Operational Evaluation 2001 12km MM5:
Status of Evaluation to Date

	Qualitative	Operational	Phenomenological
Synoptic Pattern (surface)	Y	Y	
Synoptic Pattern (aloft)	Y	Limited	
Temperatures		Y	
Water Vapor Mixing Ratio		TBD	
Wind Speed		Y	
Wind Direction		Y	
Clouds	Limited	TBD	
Radiation		Limited	
Precipitation	Y		
PBL height & evolution		TBD	
Regional analyses		Y	Y
Met Cluster analyses		TBD	TBD
Diurnal analyses		Y	Y
Range-based analyses		Y	Y
Tracer-trajectory analyses			TBD
Sea-breeze			Limited
Low-level jet			Limited

Operational Evaluation 2001 12km MM5:
Key Conclusions to Date

- **Qualitative comparisons of synoptic patterns and operational evaluation indicate that the model is a reasonable approximation of the actual meteorology that occurred during the modeling period.**
  - **Neither too fast not too slow in estimating frontal passages.**
  - **Model-derived radar reflectivity tends to underestimate the extent, but capture the general pattern of the precipitation.**

- **Caution should be exercised when using AQM results west of 100-105 degrees longitude west.**
  - **Model errors/biases are much larger in this mountainous region than over any other part of the MM5 modeling domain.**

- **While precipitation patterns are generally well-captured w/in the 12km 2001 MM5 modeling, daily/hourly differences will produce large differences in model vs. ambient AQ concentrations.**

Operational Evaluation 2001 12km MM5:
Key Conclusions to Date

- **In seasons other than winter, temperatures are underestimated during the day and overestimated at night.**
  - **This may lead to weaker model nocturnal inversions than observed**
  - **Also the underestimate of diurnal temperature change (T_{max}-T_{min}) may lead to AQ model biases as a function of the diurnal cycle.**

- **Some caution should be exercised when using AQM results in coastal regions.**
  - **Model errors/biases are slightly larger in these regions.**

- **Temperatures are underestimated during the winter.**
  - **Consistent diurnal bias of approximately 1 deg C.**

Operational Evaluation 2001 12km MM5:
Key Conclusions to Date

- **Limited aloft data indicates that average patterns are well captured**
  - **Some evidence that low level jets in Plains are not well captured**

- **Apparent tendency to underestimate solar radiation which could affect rate of chemical reactions.**
  - **Based on very limited data … few sites, few periods.**